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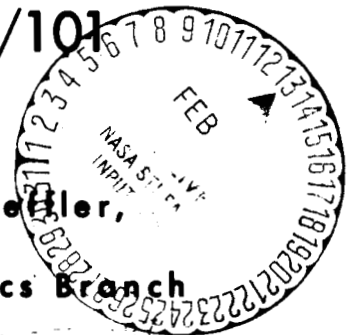
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NAVIGATION ERROR ANALYSES OF
THE FIRST RENDEZVOUS SEQUENCE
OF AS-205/101

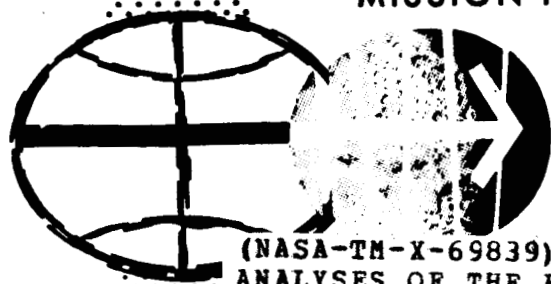
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ANALYSES OF THE FIRST RENDEZVOUS SEQUENCE
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PROJECT APOLLO

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RENDEZVOUS SEQUENCE OF AS-205/101

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NAVIGATION ERROR ANALYSES OF THE FIRST RENDEZVOUS SEQUENCE OF AS-205/101

By Jack H. Shreffler

SUMMARY

Error analyses have been performed to evaluate rendezvous navigation capabilities during AS-205/101 using intervehicular sextant tracking following a Manned Space Flight Network (MSFN) navigation update of the command and service modules (CSM) onboard computer. In the three distinct cases considered, MSFN updates occur before coelliptic sequence initiation (NCC), coelliptic maneuver (NSR), and terminal phase initiation (TPI). The lengths of the intervehicular tracking periods were varied in the pre-NCC update case to determine an optimal tracking scheme.

The pre-NCC update results in a 3 σ velocity uncertainty of 8 fps at TPI. A drag bias of about 1 fps may be expected. Updating prior to NSR would give a velocity uncertainty of 4 fps and a drag bias of 3 fps. A MSFN update prior to TPI would yield a velocity uncertainty of only 1.3 fps and a drag bias of 1 fps.

For navigational accuracy, then, the pre-TPI update is the most desirable, but allows almost no time to check out and evaluate the onboard system as does the pre-NCC update. Of course, the sextant data could be taken and recorded onboard according to the pre-NCC update plan even though a pre-TPI update is performed. Then a postflight evaluation could determine the sextant's navigational capability.

INTRODUCTION

The AS-205/101 rendezvous sequence is described in reference 1. The current rendezvous plan, which differs only slightly, is found in reference 2. The nominal navigation plan consists of a pre-NCC update of the onboard computer, with the state vectors of both the CSM and S-IVB being determined by three orbits of MSFN tracking. Onboard sextant observations commence after NCC and supply the entire navigation support for calculating the TPI maneuver (see fig. 1).

Two additional cases were considered where MSFN updates were performed prior to NSR and prior to TPI. Thus, these rendezvous sequences depend more heavily on ground navigation support.

ANALYSIS

The program used in these studies is a linear error analysis program capable of treating the simulated onboard tracking measurements in a manner equivalent to the technique employed by the onboard computer.

Pre-NCC Update

The onboard computer was assumed to be updated at 25:35 (hr:min) g.e.t. from Bermuda based on three orbits of MSFN tracking of the CSM and S-IVB. About 80 percent of the available tracking was concentrated on the active CSM; tracking was made assuming the S-IVB had a C-band beacon.

Rendezvous Sequence

Event	Initiation time, hr:min g.e.t.
MSFN update	25:35
NCC burn	26:16
Sextant tracking (30 marks)	26:26
Sextant tracking (5 marks)	27:22
NSR burn	27:53
Sextant tracking (15 marks)	28:08
TPI burn	28:54
Sextant tracking (6 marks)	28:59
MCC	29:14
TPF	29:29

Sextant marks are spaced 1.25 minutes apart.

In addition to running this nominal case, fifteen subcases were evaluated where the number of marks taken after NSR and TPI were varied. The number of marks taken after NSR was varied from 9, 12, 15 to 18, and the number taken after TPI was varied from 3, 6, 9, to 12.

Pre-NSR Update

MSFN tracking of both vehicles was continued to 27:07 (hr:min) g.e.t.
The onboard computer was updated from Ascension.

Rendezvous Sequence

Event	Initiation time, hr:min g.e.t.
NCC burn	26:16
MSFN update	27:20
Sextant tracking (5 marks)	27:22
NSR burn	27:53
Sextant tracking (15 marks)	28:08
TPI burn	28:54
Sextant tracking (6 marks)	28:59
MCC	29:14
TPF	29:29

Pre-TPI Update

MSFN tracking of both vehicles was continued to 28:38 (hr:min) g.e.t.
The onboard computer was updated from Antigua.

Rendezvous Sequence

Event	Initiation time, hr:min g.e.t.
NCC burn	26:16
NSR burn	27:53
MSFN update	28:43

TPI burn	28:54
Sextant tracking (6 marks)	28:59
MCC	29:14
TPF	29:29

Sources of Relative State Uncertainties

The following parameters were assumed to affect the uncertainties in the relative state during each rendezvous sequence:

1. 1 σ noise on intervehicular measurement of sextant angles, 0.0002 radians.
2. Bias on intervehicular measurement of sextant angles, 0.0002 radians.
3. Uncertainty in μ of the earth - $\sigma^2 = 1.1236 \times 10^{22} \text{ (ft}^3/\text{sec}^2)^2$.
4. Drag uncertainty on both vehicles (10 percent of the total drag)

CSM	$\sigma^2 = 14.83 \times 10^{-12} \text{ (ft/sec}^2)^2$
S-IVB	$\sigma^2 = 1974. \times 10^{-12} \text{ (ft/sec}^2)^2$

In the pre-NSR and pre-TPI update cases, the drag uncertainty was assumed to be 100 percent of the total after the update. This is actually a more appropriate assumption since the onboard computer assumes no drag. This 100 percent uncertainty is then considered as a drag bias.

5. Misalignment in IMU axes due to initial misalignment and drift - $\sigma = 7.8 \times 10^{-4}$ radians in each axis.

6. Burn errors - no burn errors were assumed for the pre-NCC update case. For the pre-NSR update case, a burn error of 5 fps in each velocity axis was assumed at NCC and 0.7 fps at NSR. A burn error of 5 fps in each velocity axis was assumed for both NCC and NSR in the pre-TPI update case. The rationale for these choices is that the onboard system is able to accurately monitor the burns, but, before the MSFN update, the ground does not have benefit of the onboard knowledge.

7. The MSFN station location biases, measurement biases, and noise are those found in reference 3.

The following stations tracked the CSM during the rendezvous (to be included in pre-NSR update):

Station	Radar	Time, hr:min g.e.t.
HAW	S-band	26:40.7 - 26:45.7
GYM	S-band	26:52.0 - 26:57.4
CNV	S-band	26:58.5 - 27:04.7
GBI	C-band	26:59.1 - 27:05.2
ANT	S-band	27:05.0 - 27:10.0

The following additional stations were included in pre-TPI update:

Station	Radar	Time, hr:min g.e.t.
HAW	S-band	28:15.4 - 28:20.2
GYM	S-band	28:26.8 - 28:32.0
CNV	S-band	28:33.7 - 28:38.0

The following stations tracked the S-IVB during the rendezvous sequence (to be included in pre-NSR update):

Station	Radar	Time, hr:min g.e.t.
HAW	C-band	26:40.7 - 26:46.1
CNV	C-band	26:59.0 - 27:04.6
BDA	C-band	27:02.8 - 27:06.9
ANT	C-band	27:04.6 - 27:09.5

The additional stations included in pre-TPI update follow:

Station	Radar	Time, hr:min g.e.t.
HAW	C-band	28:15.0 - 28:20.1
CNV	C-band	28:33.4 - 28:38.0
GBI	C-band	28:34.0 - 28:38.0

RESULTS

Figure 2 gives the 3σ position and velocity uncertainties for the nominal case from NCC-plus-10-minutes to NSR-plus-15-minutes. Figure 3 displays 3σ uncertainties from NSR-plus-15-minutes, after the marks have been processed, to TPI-plus-5-minutes. The effects of taking 9, 12, 15, and 18 marks are shown. Figures 4, 5, 6, and 7 give uncertainties from TPI-plus-5-minutes, after the marks have been processed, to TPF assuming the number of marks taken at NSR-plus-15-minutes was 9, 12, 15, and 18, respectively. The effects of taking 3, 6, 9, and 12 marks at TPI-plus-5-minutes are shown.

Since this study was completed the onboard program has been modified to allow sextant marks to be taken more frequently than one per minute. However, some preliminary investigations suggest that the length of the data arc is more important than the rate of measurements. That is, 15 marks taken in 1 minute would not be as beneficial as 15 marks taken in 15 minutes. Therefore, when referring to the number of marks taken it should be noted that they are spaced 1.25 minutes apart in this analysis.

Figures 8 and 9 give the 3σ relative velocity and position uncertainties for the pre-NSR update case. Figure 8 covers the period from NCC-plus-66-minutes to TPI and figure 9 from TPI-plus-5-minutes to TPF.

Figure 10 gives 3σ relative uncertainties for the pre-TPI update case from TPI to TPF.

In the pre-NSR and pre-TPI update cases, the effect of 100 percent drag uncertainty was considered separately. This effect is interpreted as a drag bias and is presented in these figures.

CONCLUSIONS

Considering the pre-NCC update case, the nominal plan and its fifteen subcases, it is apparent that at least 15, and probably 18 or more, marks should be taken after NSR. The TPI uncertainties drop 60 percent when going from 9 marks to 12 marks, 30 percent when going from 12 marks to 15 marks, and 10 percent when going from 15 marks to 18 marks. Similar decreases in uncertainties are observed at MCC and TPF provided the nominal 6 marks are taken during post-TPI tracking.

It is clear that 6 marks are required after TPI and that additional marks offer no advantage.

The sextant has one outstanding property. Its use generally makes the uncertainties propagate downward (decrease). This effect may be seen after NSR-plus-15-minutes, for example.

Updating prior to TPI would give a 3σ velocity uncertainty of 1.3 fps at TPI. This is vastly superior to the other two cases. It is, therefore, recommended that the TPI maneuver be based only on MSFN tracking prior to TPI. Sextant marks may be taken and recorded and a post-flight analysis made to determine the navigational capability using the sextant.

Taking sextant marks after TPI drastically reduces the drag biases and has a noticeable effect upon relative state uncertainties. Reference 4 presents results of a navigational error analysis study performed by McDonnell on AS-205 which indicates that this is the principle effect of taking sextant marks at other tracking periods. Therefore, periodic sextant tracking is desirable to reduce velocity and position drag biases.

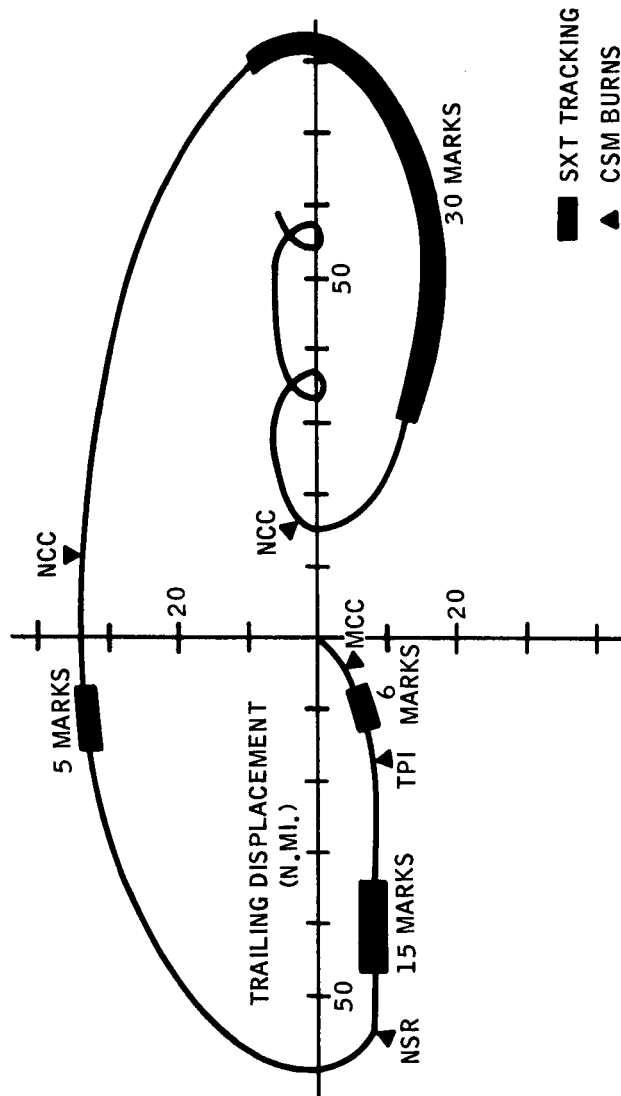


Figure 1.- AS-205/101 rendezvous procedures plan (CSM relative to S-IVB).

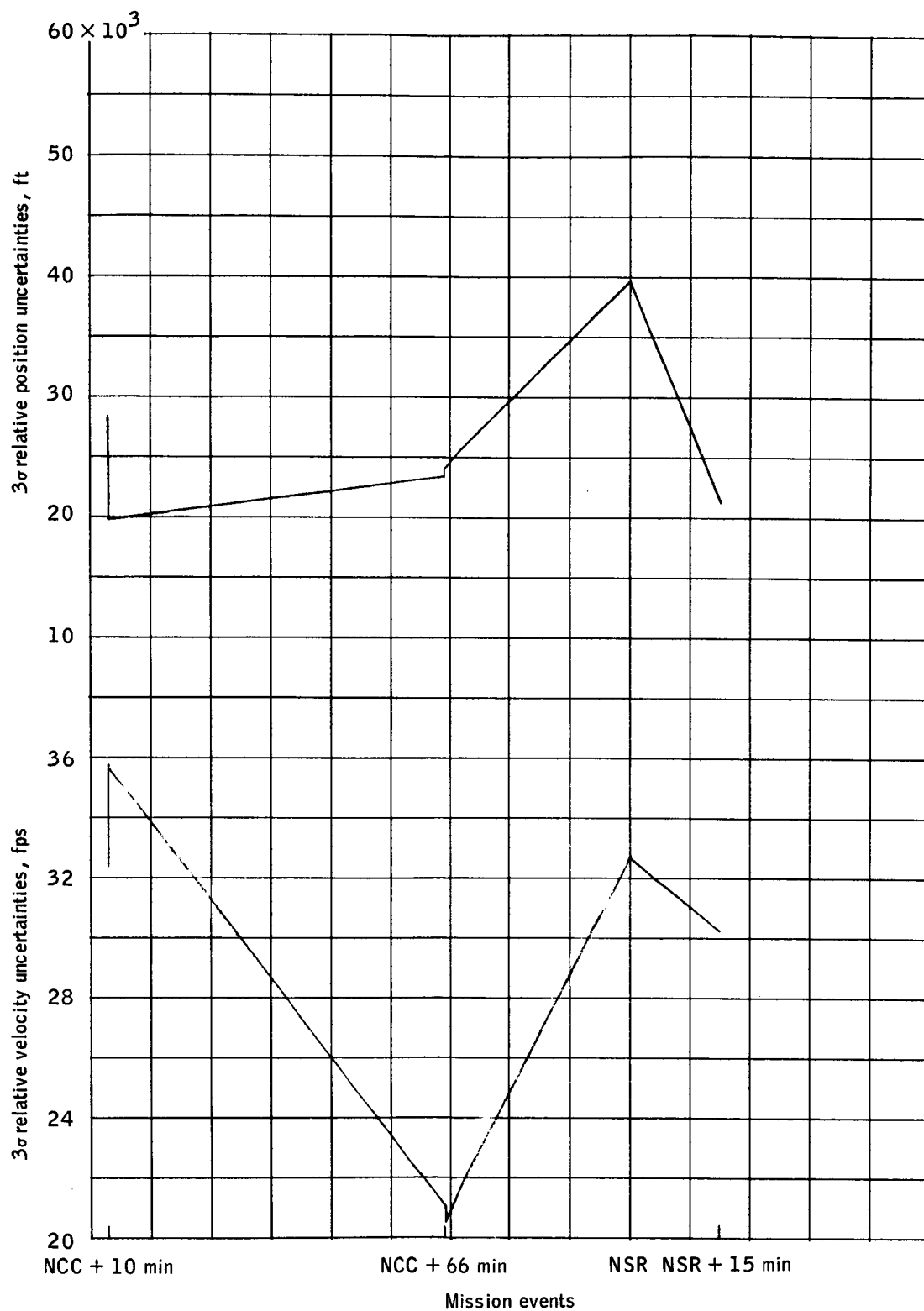


Figure 2.- Pre-NCC update-relative uncertainties, NCC+10 to NSR+15.

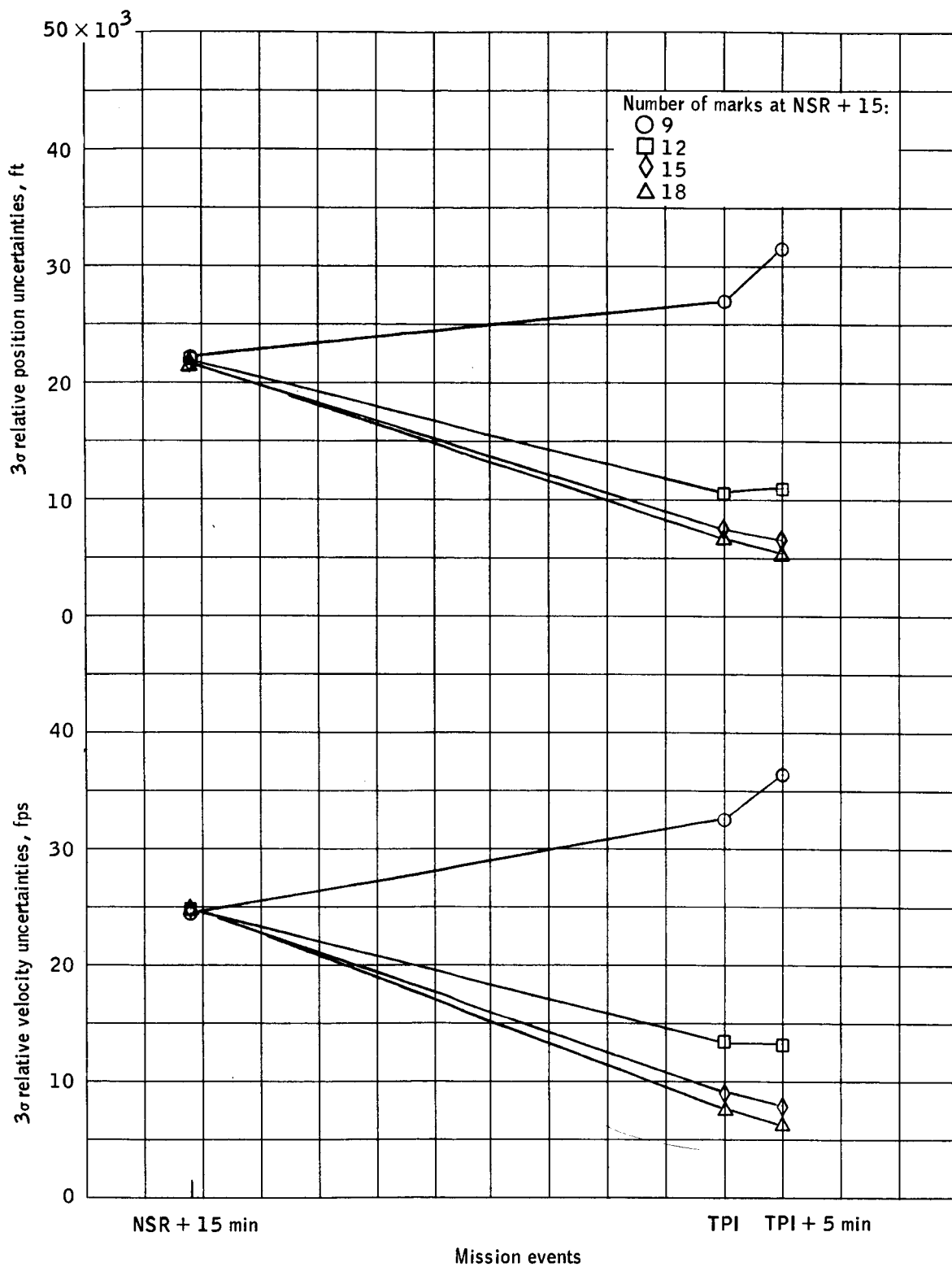


Figure 3.- Pre-NCC update-relative uncertainties, NSR+15 to TPI+5.

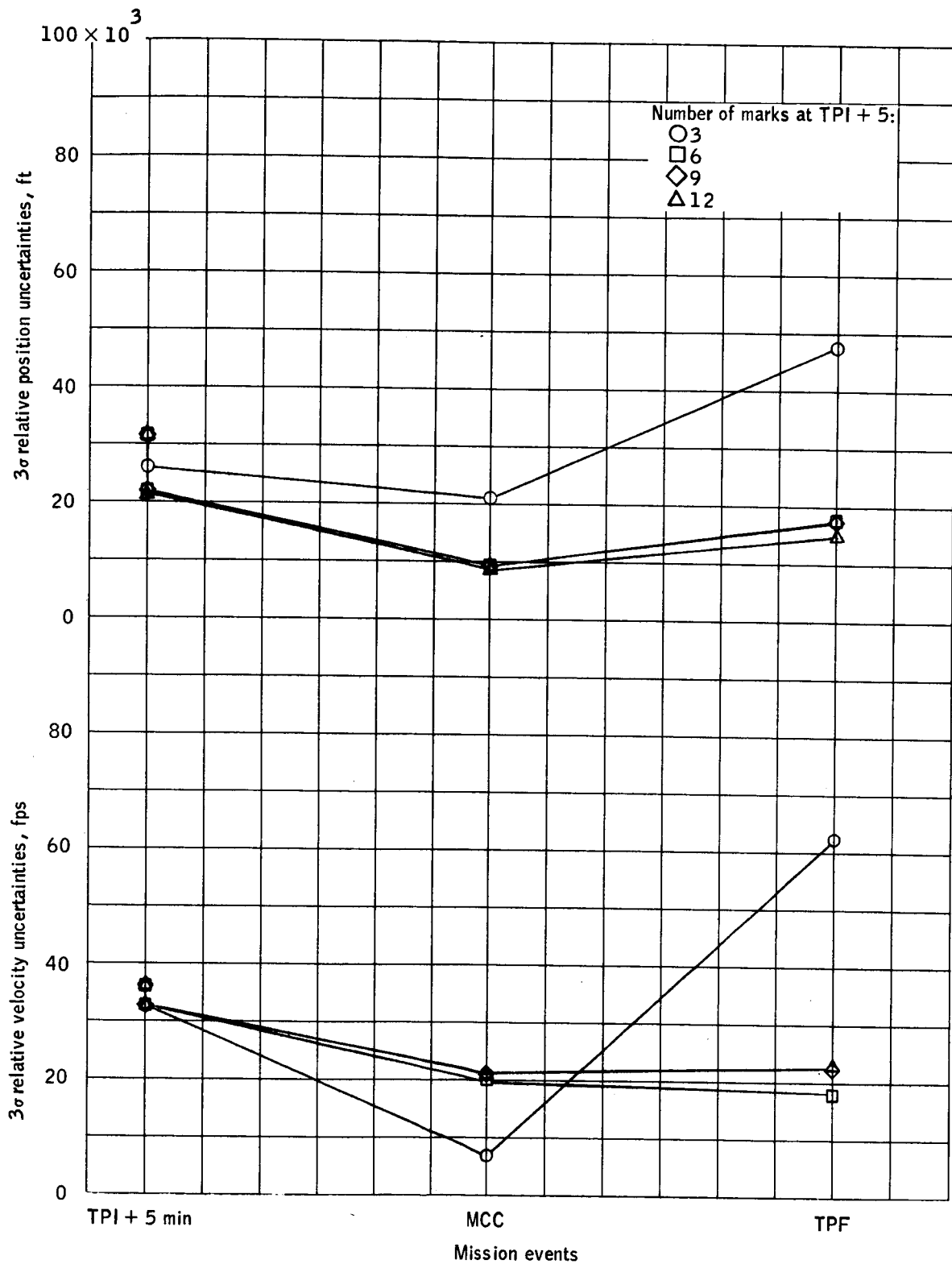


Figure 4.- Pre-NCC update-relative uncertainties, TPI+5 to TPF, assuming 9 marks taken at NSR+15.

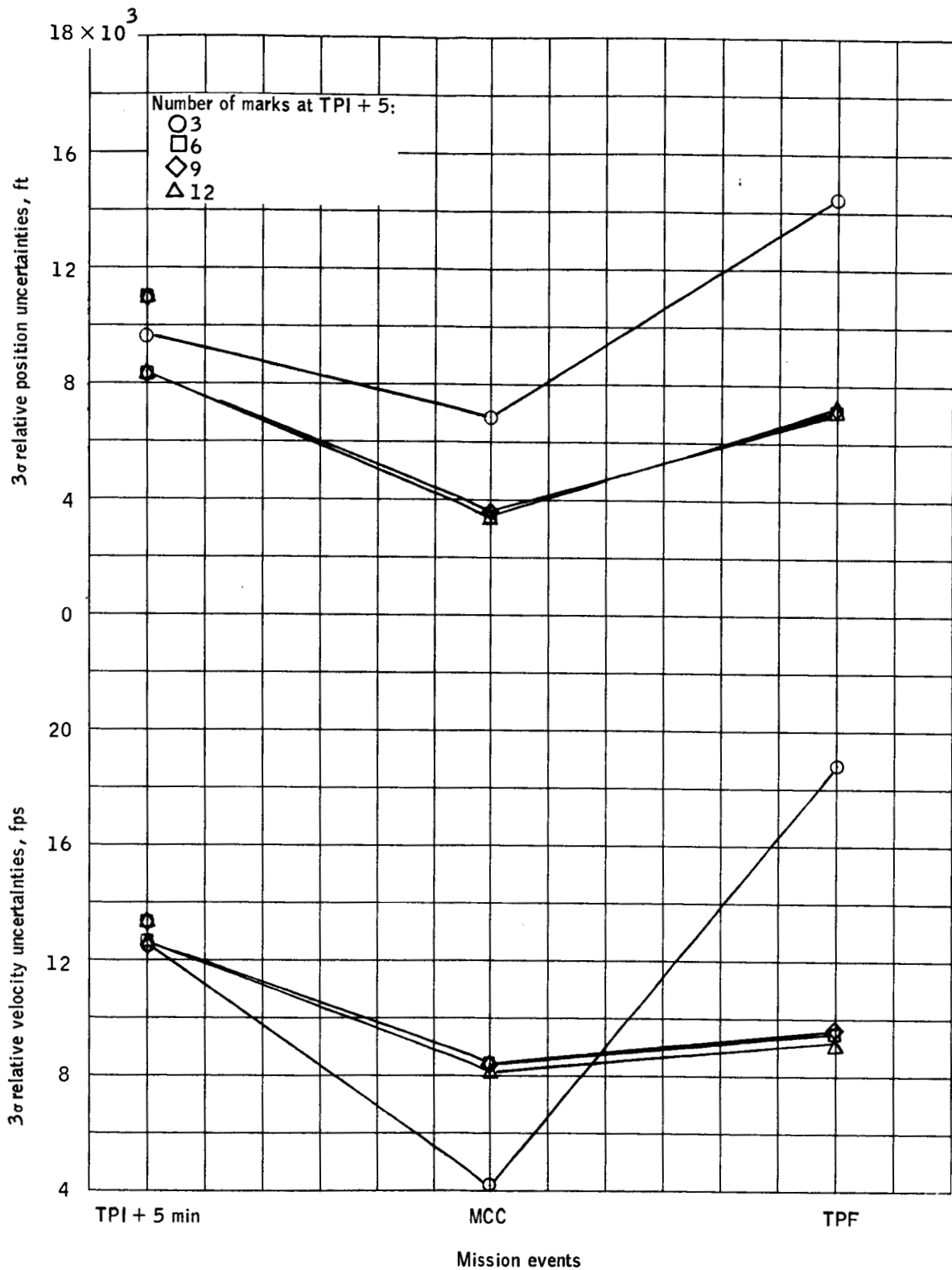


Figure 5.- Pre-NCC update relative uncertainties, TPI+5 to TPF, assuming 12 marks taken at NSR+15.

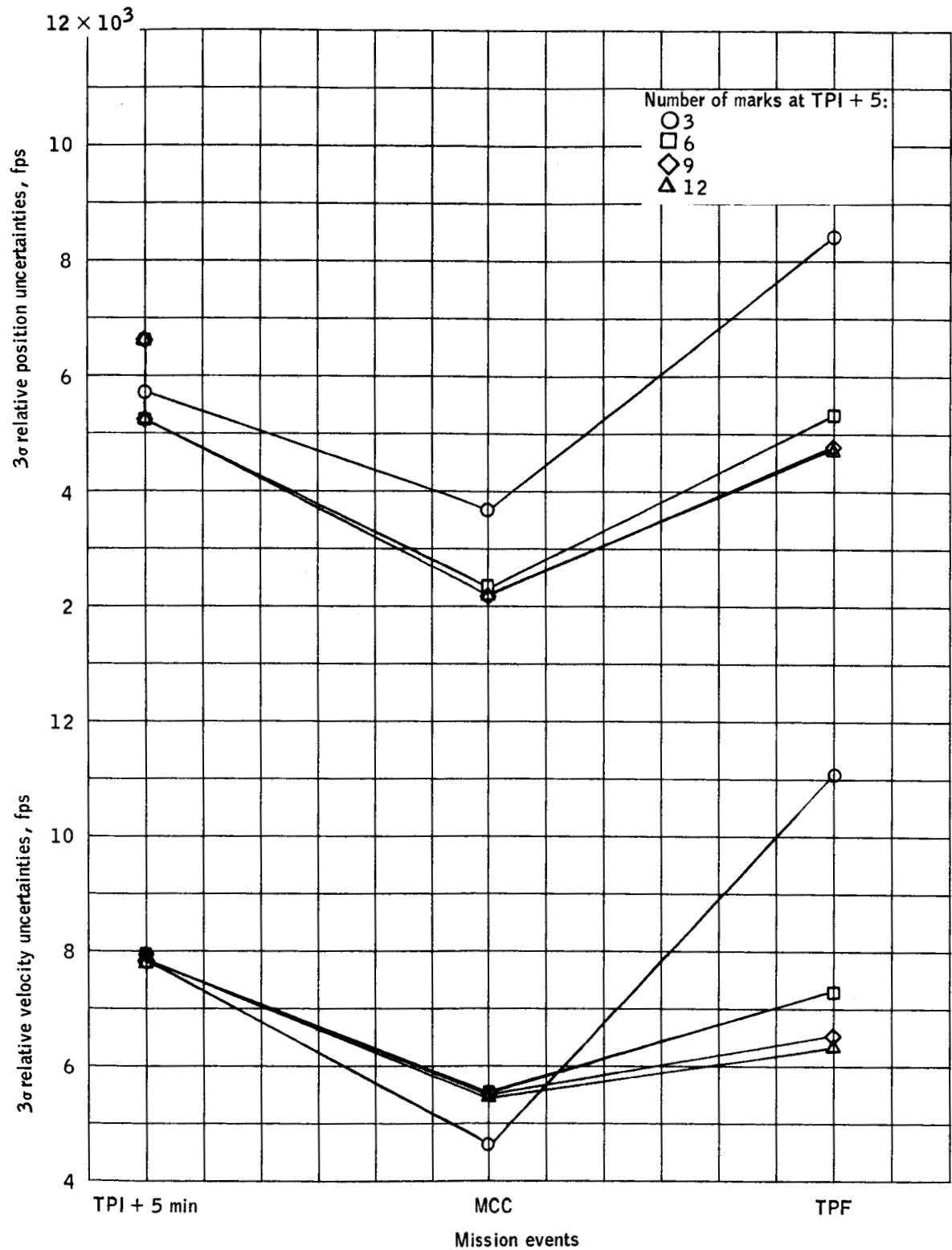


Figure 6.- Pre-NCC update-relative uncertainties, TPI+5 to TPF, assuming 15 marks taken at NSR+15.

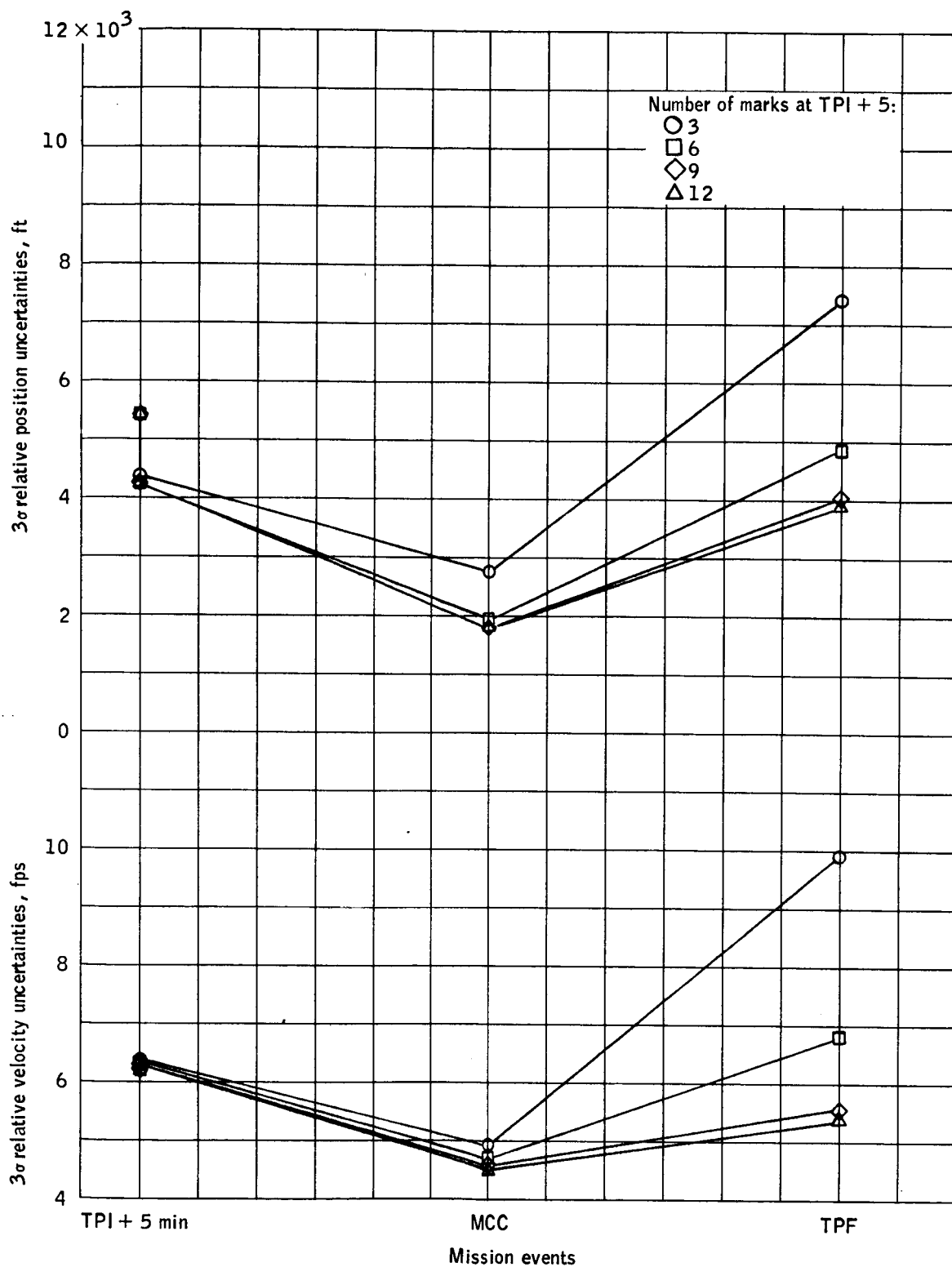


Figure 7.- Pre-NCC update-relative uncertainties, TPI+5 to TPF, assuming 18 marks taken at NSR+15.

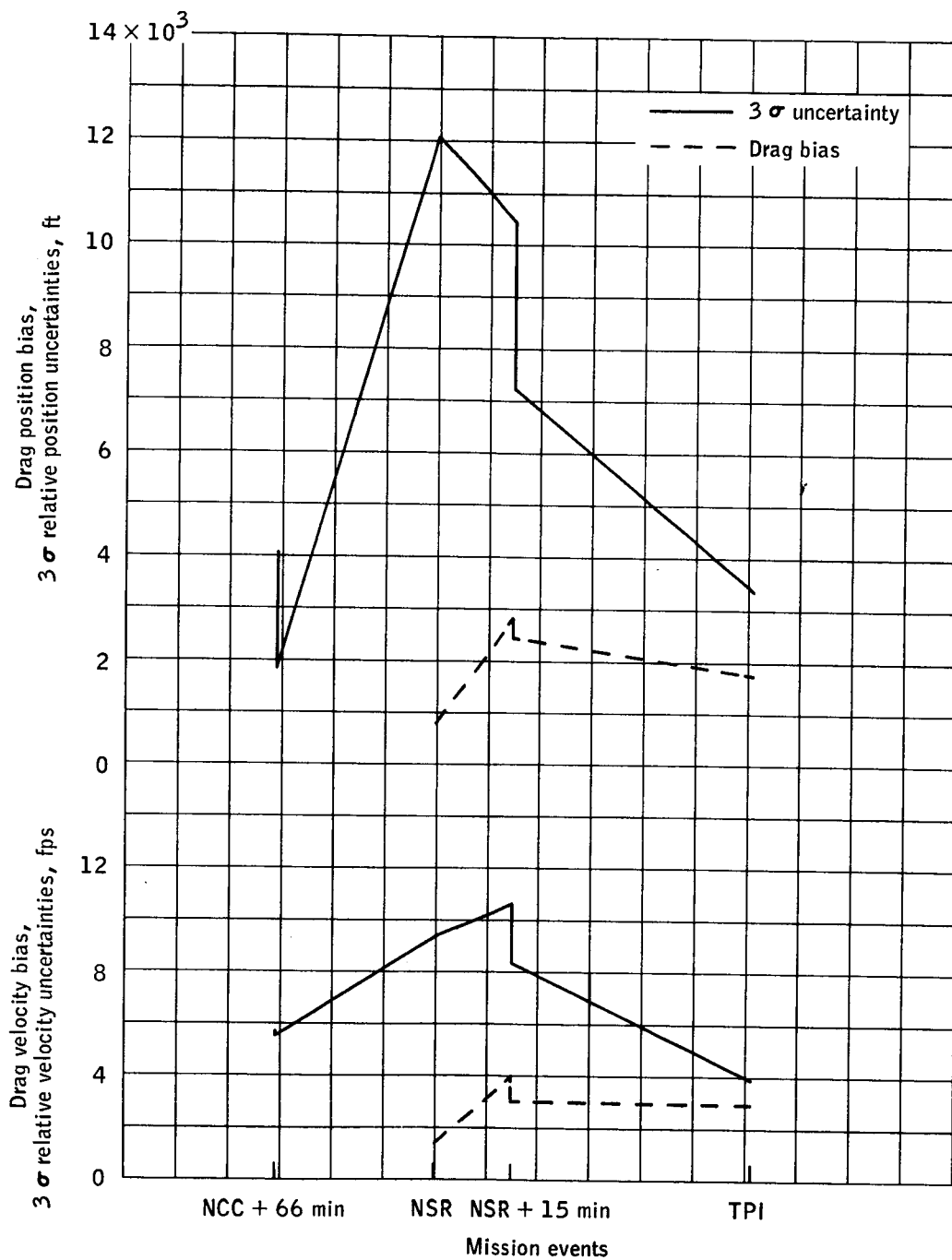


Figure 8.- Pre-NSR update-relative uncertainties and drag biases , NCC+66 to TPI.

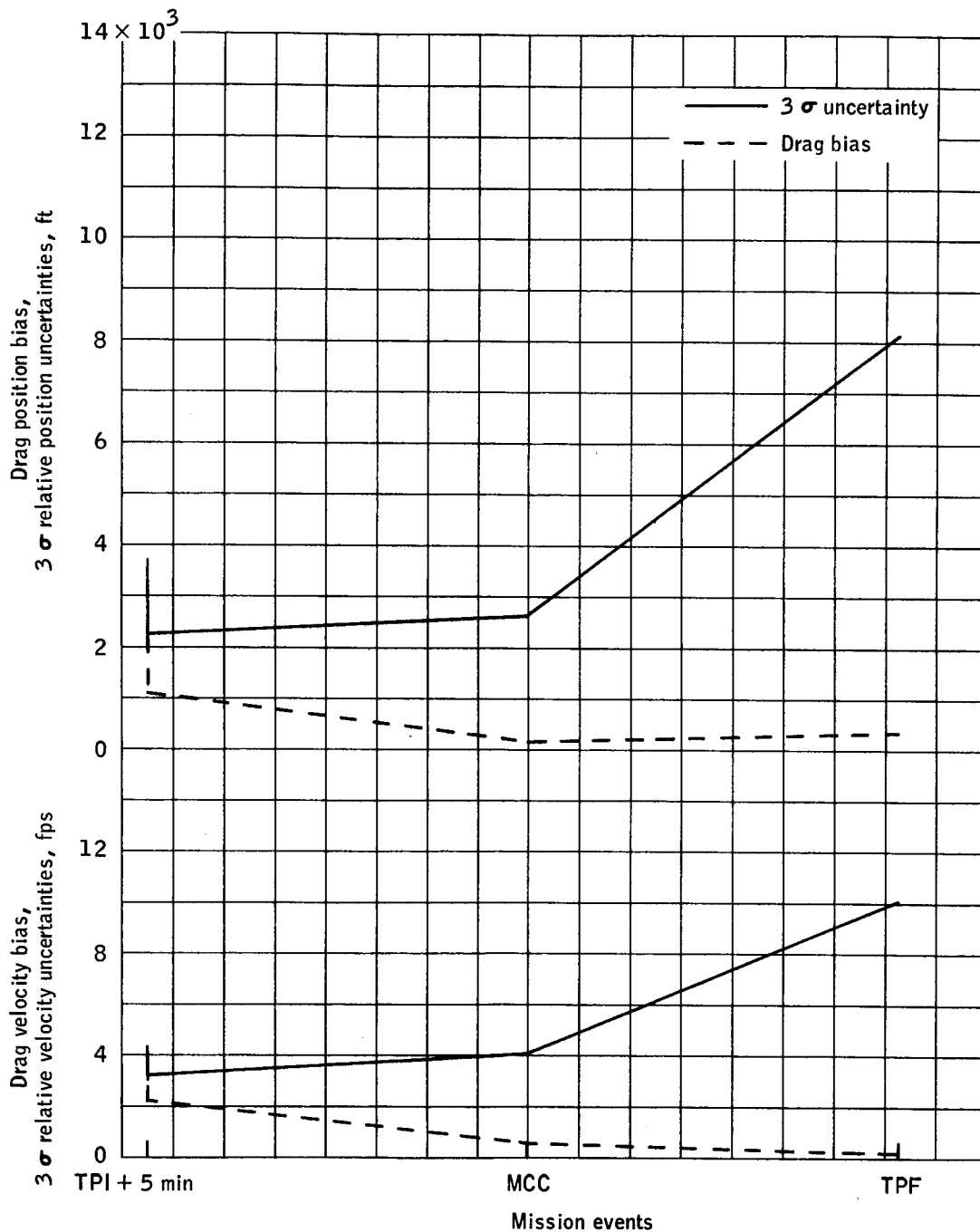


Figure 9.- Pre-NSR update-relative uncertainties and drag biases, TPI+5 to TPF.

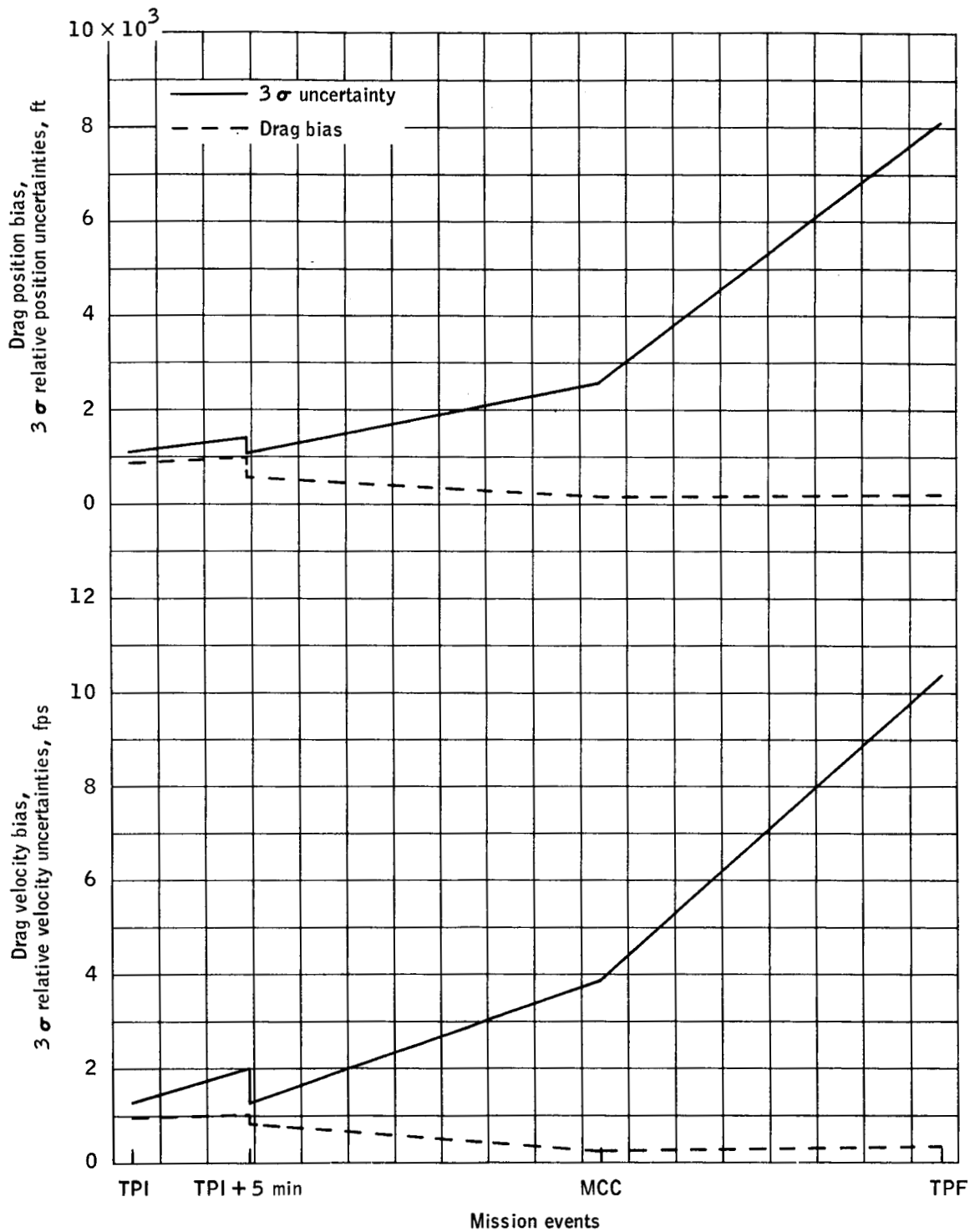


Figure 10.- Pre-TPI update-relative uncertainties and drag biases, TPI to TPF.

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1. Young, Ken: Apollo 205/101 Rendezvous Study. MPAD Memorandum No. 67-FM62-70, May 22, 1967.
2. Young, Ken: Current AS-205/101 Rendezvous Profile. MPAD Memorandum No. 67-FM64-158, September 21, 1967.
3. Apollo Navigation Working Group: Technical Report No. AN-1.2, January 17, 1967.
4. Dugge, Peggy M.: W-Matrix Initialization Schedule for the Optimum W-Matrix for the Apollo VII Rendezvous. McDonnell Astronautics Company, Apollo Flight Crew Support, Apollo Design Note No. 70, November 27, 1967.